# Smooth Particle Hydrodynamics for Surf Zone Waves

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## LONG-TERM GOALS

Smoothed Particle Hydrodynamics (SPH) is a meshless numerical method that is being developed for the study of nearshore waves and Navy needs.   The Lagrangian nature of SPH allows the modeling of wave breaking, splash-up, and the subsequent fluid turbulence, which in large part is comprised of coherent turbulent structures.

## OBJECTIVES

The objectives of this project are to improve the SPH model for use in unraveling the physics of breaking waves, including the description of the wave-induced turbulence and sediment transport within the surf zone.

## APPROACH

The approach is based on improving various aspects of the SPH code; applying the code to more validation tests; and to examine in some detail new aspects of the model by applying it to different situations. The development of a hybrid model, that is, coupling the SPH particle model to a conventional finite difference model  (a Boussinesq model, FUNWAVE)  is being explored.

## WORK COMPLETED

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- An examination of errors associated with the choice of various time integration schemes and choice of kernel in the SPH method.

- Validation of the SPH hydrodynamics calculation has been carried through additional comparisons to laboratory experiments.

- Development of a new boundary condition for the no-flow conditions, using the techniques that are being used to develop a Boussinesq-SPH hybrid wave model.
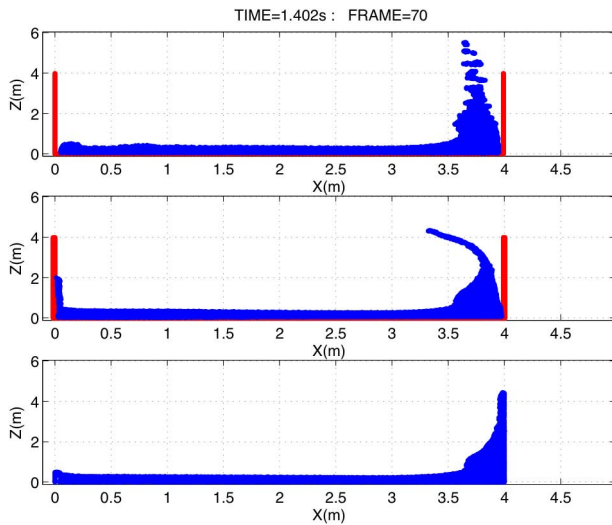
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- Validation carried out for suspended sediment transport under waves, including bed erosion.

## RESULTS

**Accuracy of the Methodology:**   SPH can use a variety of different interpolating kernels (quadratic, cubic spline, quartic and quintic truncated polynomials) and a variety of time-marching schemes. Capone, Panizzo, and Dalrymple (2007) examined  the accuracy of the various combinations of kernels and integration schemes for several test cases (2 D and 3 D), which have analytical solutions. The results show that using a more sophisticated kernel   (say, higher order polynomial kernels versus lower order polynomials), the less the overall error.  However, the study shows dramatically that if gradients calculated by SPH are corrected (Bonet and Lok, 1999),   the accuracy is greatly improved and  the accuracy is then independent of the kernel.  Apparently the gradient correction also removes some of the inaccuracy  introduced by lower order kernels.

**Boundary Condition:** Boundary conditions have also been problematic for SPH.  Monaghan (1994) and Monaghan and Kos (1999) have provided two methods based on imposing Lennard-Jones forces at fixed  particles that define the boundary. These (physically real) forces cause particles approaching the boundary to slow and then reverse course. Dalrymple and Knio (2001) introduced what are now called dynamic boundary conditions (Crespo *et al*., 2007), which are just two staggered rows of boundary particles that participate in the numerical model in all ways, except that they are not allowed to move.  It has the unfortunate property of being too sticky—fluid particles do not drain completely from vertical walls. Recently we have developed a new boundary condition,  based on our work on hybrid modeling. Using a technique from molecular dynamics (Nie *et al*.,  2004), we introduce a single row of grids along the no-flow boundaries.  Fluid particles encountering these grids have their average normal velocity constrained within the grid.  Figure 1 shows the comparison between the three boundary condition types for a dam break jet after impinging on a vertical wall.  The top figure shows the Monaghan BC, the middle the dynamic boundary condition, and fianlly the third figure is the new boundary condition.  The figure shows that the new boundary condition performs the best; the others produce too much repulsion. Applications of this new boundary condition to floating bodies is straightforward.

**Hybrid Model:** To provide a convenient way to handle large practical problems, we are working on developing a hybrid model--such as a Boussinesq wave model for the far field and SPH in the near field to handle wave breaking. This is because the Boussinesq model is far more efficient for the far field.   So far we have one-way coupling; that is, we have information transmitted to the SPH from Boussinesq model without feedback,  Narayanaswamy and Dalrymple (2005). We have been working on the fully-coupled model, yet have not quite gotten the method to work.  We are following methods developed in molecular dynamics by Nie and JHU colleagues, wherein an overlap region exists between the two models.  The trick is the method of transferring information between the models in

this region, since one Boussinesq finite difference point corresponds to many SPH particles. We hope to finish this shortly.

**Suspended Sediment:** Zou and Dalrymple (2006) use an additional SPH particle equation to determine the concentration of suspended sediment due to a breaking wave. The sediment is picked up from the bottom, using a pick-up function, and then sustained in the water column by a balance between turbulence and the fall velocity of the sediment.
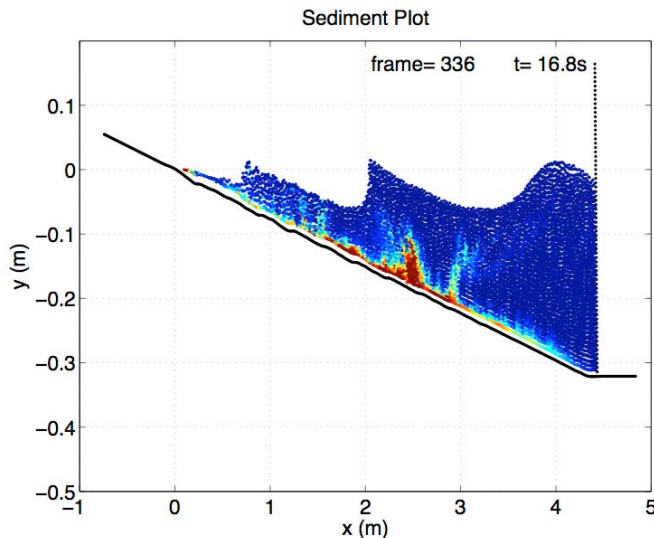


In the figure, plumes of sediment are shown rising from the bed under the breakers and deformation of the original planar beach is shown. (Note distorted scale of the figure.) Dr. Zou completed his Ph.D. at Johns Hopkins University in June, 2007.

International Collaborations: Our international collaborations with the Universities of Vigo (Gómez-Gesteira and Crespo), Rome (Panizzo, Capone), and Manchester (Rogers) have led to the release of an open source code, SPHysics (originally JHUSPH, then SPHYNX) on August 1, 2007. The purpose of the public release of the source code ( along with a users manual, test examples, and post-processing tools) was to allow others to learn SPH easily, but also to perhaps induce them to participate in the improvement of the modularized codes. The URL is: http://wiki.manchester.ac.uk/sphysics . The code has been downloaded over 70 times.

## IMPACT/APPLICATIONS

Smoothed Particle Hydrodynamics is proving to be a competent modeling scheme for free surface flows in two and three dimensions. Coupled with another wider-area wave model, such as Boussinesq, a hybrid SPH model would provide a large, highly resolved, look at an entire surf zone.

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